

AMS : A PARTICLE OBSERVATORY IN SPACE

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The expected physics and astrophysics capabilities of the AMS experiment on board the International Space Station are briefly reviewed.

1 Introduction

The AMS spectrometer will be implemented on the International Space Station at the end of 2003 (or beginning of 2004). The instrument will be made of a superconducting magnet which inner volume will be mapped with a tracker consisting of 8 planes of silicon microstrips surrounded by several sub-detectors: a time-of-flight (TOF), a ring imaging Cherenkov (RICH), an electromagnetic calorimeter (ECAL), a transition radiation detector (TRD) and, possibly, a synchrotron radiation detector (SRD). The expected performances will be reviewed together with the physics goals : high statistics study of cosmic rays in a wide range of energies, search for primordial antimatter, search for non-baryonic dark matter and, to some extent, gamma-ray astrophysics.

A simplified version of the spectrometer has already been flown during a precursor flight (june 2-12, 1998) on the Space Shuttle Discovery. The technical success together with the first physics results and their interpretation will be briefly reviewed.

2 The spectrometer

The AMS spectrometer Fig.1 will be based on a superconducting magnet which maximum field should be of the order of 1 Tesla, perpendicular to the axis of the cylinder. Its inner volume will be filled with 8 layers of double sided silicon tracker measuring the trajectory of

AMS 02

In Cargo Bay

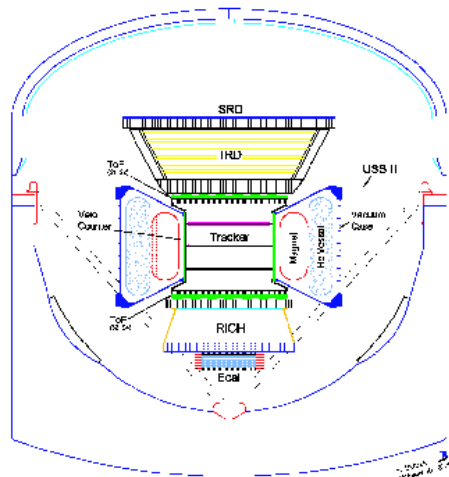


Figure 1: the AMS spectrometer (to be implemented on the ISS)

the charged particles and, therefore, their rigidity (from around 300 MV up to 3 TV). The time of flight system has its planes at each end of the magnet, covering the outer tracker layers. It provides information on the particles transit time and will be used both as a trigger for the whole experiment and as a measurement of the velocity for low energy events. The transition radiation detector will be useful to improve the lepton/hadron discrimination up to the proton threshold around 300 GeV. A three-dimensional sampling electromagnetic calorimeter will measure γ , e^+ and e^- energies and increase the lepton/hadron rejection factor to 10^3 (on a limited fraction on the acceptance). Finally, the ring imaging Cherenkov detector will allow precise measurements of the velocity $\Delta\beta/\beta \approx 10^{-3}$ together with a charge determination up to $Z \approx 20$.

3 Cosmic-ray astrophysics

Cosmic rays are a part of the galactic components which reflects the dynamical equilibrium of the physical system they belong to, carrying out very important informations on the galactic medium, its population, structure, and history. In particular, it has been recently shown¹ that measurements of cosmic nuclei give strong constraints on the diffusion parameters and rule out some models (*e.g.* those without convection or reacceleration and Kolmogorov spectra for the diffusion coefficient).

The AMS experiment will dramatically improve the situation, allowing a high statistics study of many cosmic ray species including e^+ , e^- , p , \bar{p} , and the lightest ions $d, t, {}^3\text{He}, {}^4\text{He}$. Heavier light ions will also be studied with mass identification up to $A \approx 20$, and elements up to $Z \approx 20$ depending on the final performances of the instrumentation of the spectrometer (RICH in particular). Unstable ions like ${}^{10}\text{Be}$, and ${}^{26}\text{Al}$ are of particular interest since they provide a measurement of the time of confinement of charged particles in the galaxy (galactic chronometers)². The corresponding antimatter nuclei will be searched with equivalent instrumental performances in identification and kinematic range. The metrological perspectives are summarized in table 1 borrowed from Buenerd, 2001⁴.

Basically the spectrometer will be able to accumulate statistics larger by 3 to 4 orders of magnitude than those measured so far by other space-borne experiments, for all the species

Particles	P_{min}	P_{max}	Comments
e^-	≈ 0.3	≈ 3000	Upper limit set by rigidity resolution
e^+	≈ 0.3	≈ 300	Upper limit set by TRD
proton	≈ 0.3	≈ 3000	Upper limit set by rigidity resolution
Charge identification of elements			
Ions $Z < \approx 20$	≈ 0.3	≈ 1500	set by RICH performances
Mass identification of isotopes			
Ions $A < 4$	1 to 4	≈ 20	set by RICH performances
Ions $4 < A < \approx 20$	1 to 4	≈ 12	
Antimatter			
\bar{p}	≈ 0.3	≈ 3000	Depending on \bar{p}/e^- discrimination
\overline{ions}	≈ 0.3	≈ 1500	$\overline{He}, \overline{C}$

Table 1: *Summary of the particle detection and identification range of the AMS02 spectrometer. The upper instrumental limits are set either by the momentum measurement accuracy (at the highest momenta) or by the range of identification of the particle. The lower values are set by the low momentum cutoff of the magnetic spectrometer or by the range of particles in detectors, or by threshold effects. Statistical limits are ignored. The given numbers should be considered as orders of magnitudes. The true limits will depend critically on the relative statistics of the particles to be identified versus background particles, like e^+/p or \bar{p}/e^- . The momenta are given in GeV/c or GeV/c per nucleon when applicable.*

studied. Figure 2 gives the expected statistics for the ^{10}Be isotope for 6 weeks of counting from a simulation using the RICH of AMS and the previous measurements (points of the lower left edge of the plot)².

4 Search for dark-matter and "new-physics"

It is now well known that stars are less than 1% of the mass-energy content of the Universe. Baryons, whose density can be inferred from deuterium abundance measurements in high-redshift hydrogen clouds within the Big-Bang nucleosynthesis model, should contribute around 5% (this value is in agreement with several other independent estimates). Non-baryonic dark matter can be measured in rich clusters, comparing the total mass (given by the motion of galaxies or by weak lensing) with the gas mass (given by X-ray flux or by Sunyaev-Zel'dovich CMB distortion). The resulting density is around 40% (which is consistent with a variety of other methods involving different physics). As a conclusion, the non-baryonic content of the Universe seems to be much more important than the baryonic one³. One of the best candidates for this unknown component would be long-lived, weak-interacting massive particles : exactly what could be expected from relic neutralinos if R-parity is conserved. AMS will look for dark matter through the annihilation of neutralinos, expected to "enrich" the \bar{p} and e^+ spectra. Recent studies have shown that the \bar{p} flux should, unfortunately, not be substantially distorted by this source-term, due to non-annihilating inelastic scattering of secondary antiprotons and to nuclei-induced antiproton creation^{5,6}. On the other hand, the secondary-antiproton spectrum is now computed with great accuracy⁷, allowing a good sensitivity to the absolute normalisation of the spectrum and not only to its shape. Stringent upper limits on some supersymmetric models (if not a positive detection) could, this way, be derived with AMS-data. Furthermore, antideuterons⁸ have also been shown to be a powerful tool to study neutralinos annihilation (due to a tiny secondary cosmic background, mostly for kinematical reasons) if the instrumental background (due to mis-reconstructed deuterons and anti-protons events) can be lowered enough. This latter point is quite unlikely. Finally some "exotic" astrophysical objects, like

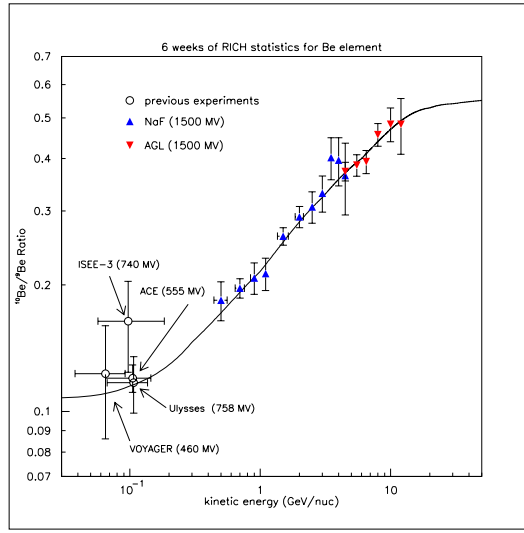


Figure 2: Expected statistics for the ^{10}Be isotope for 6 weeks of counting with AMS.

primordial black holes⁹, can be very efficiently looked for through the antiprotons emission¹⁰.

From a technical point of view, it will also be extremely useful to have the same detector measuring, for the first time, both the cosmic nuclei (to constrain the diffusion model) and the antiproton spectra.

5 Search for primordial antimatter

The laws of fundamental physics being nearly the same for matter and antimatter, the picture of a symmetric Universe made of a "patchwork" of regions of both types is very tempting. Theoretical works¹¹ have shown that, in such a model, gamma-rays induced by annihilation after recombination would exceed the observational limits. On the other hand, direct measurements cannot exclude the presence of antimatter on scales larger than the typical size of galactic clusters, around 20 Mpc. By trying to measure **directly** anti-nuclei in cosmic rays, AMS will be in position to strongly confirm the standard prediction or, possibly, to point out some unknown phenomena. Nevertheless, whereas a positive detection ($Z > 2$) would be clearly conclusive, an upper limit on the amount of anti-nuclei in cosmic rays would be difficult to be turned out into a lower limit on the domain size because of large uncertainties on the structure and intensity of extragalactic magnetic fields.

Anyway, it should be noted that the experiment will also be very sensitive to potential anti-globular clusters within our Galaxy¹².

6 Gamma-ray astrophysics

Gamma-rays are not only interesting for astrophysical purposes (pulsars, SNRs, AGNs, GRBs, CIB constraints, etc...) but also for the previously quoted search for neutralinos annihilations¹³.

The AMS detector was not designed for gamma-ray astrophysics. In particular, it cannot be pointed toward the sources. Nevertheless, together with AGILE and waiting for GLAST, it could feature some interesting gamma-ray capabilities¹⁴. Between 0.3 and 50 GeV, the angular resolution would be around $0.8^\circ (E/1\text{GeV})^{-0.96}$ with a peak effective area of 1500 cm² and a flux sensitivity of the order of $0.5 \cdot 10^{-8} \text{ cm}^{-2} \text{ s}^{-1} \text{ GeV}^{-1}$ (at 1 GeV). The calorimeter could also be very usefully used for gamma-ray astronomy if it can be self-triggered.

7 AMS-I preliminary flight results

Together with excellent technical results, accurate measurements of particles flux close to Earth have been performed by the AMS experiment, bringing a body of excellent new data on the particle populations in the low altitude terrestrial environment^{15 16 17 18 19 20}. Most of those measurements were quite surprising (high sub-geomagnetic cutoff population, e^+/e^- ratio, ^3He nuclei, etc...) and are now being interpreted^{21 22}. They show that the detector worked very well and open a new era of cosmic-ray physics.

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